

The Optical Transient of GRB970228, 16 hours after the burst

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Received ; Accepted

Abstract. Until recently the positions of gamma ray bursts were not sufficiently well known within a short timescale to localize and identify them with known celestial sources. Following the historical detection of the X-ray afterglow of the burst GRB970228, extending from 30 s to 3 days after the main peak, by the Beppo-SAX satellite (Costa *et al.* 1997), and that of an optical transient ~ 21 hr after the burst (van Paradijs *et al.* 1997, hereafter VP), we report here the detection of the same optical transient, in images obtained ~ 4.5 hr hours earlier than in VP.

Key words: X-ray – Gamma Ray Burst – Optical Transient

Multiwavelength detection of GRB counterparts has been made possible recently by Beppo-SAX, the Italian-Dutch satellite for X-ray astronomy (Piro *et al.* 1995): several gamma ray bursts (GRBs) have been localized with an accuracy of ~ 3 arcmin within a few hours from their occurrence. Well-targeted follow up observations of GRBs from X-ray to radio wavelengths have thus been made within an unprecedented time lapse of less than a day (Paczynski & Wijers 1997). In the case of GRB970228,

X-ray observations with the Beppo-SAX Narrow Field Instruments have allowed further refinement of the position to within 45 arcsec, and optical searches have found a faint but undisputable Optical Transient within this small error box.

The detection of the X-ray afterglow is interpreted as evidence for highly relativistic expansion of matter ejected from an as yet undetermined source (Vietri 1997a), within the framework of the fireball model (Mészáros *et al.* 1993). The detection and monitoring of the optical counterpart is of paramount importance, because it allows source localization with highest precision and searches for a possible host. Depending on peak flux levels, spectroscopic techniques can be employed to harness much needed information on the distance scale, a still elusive topic. Also, a determination of the time-dependence of the counterpart fading can provide tests of different GRB models.

In response to the alert from the Beppo-SAX Team, we observed the field containing the (then) ~ 3 arcmin accurate position of GRB970228 with the Rome Astronomical Observatory's 0.60 m Schmidt telescope at Campo Imperatore on Feb 28.8, Mar 4.8 and Mar 12.8 UT. The telescope was equipped with a $2k \times 2k$ CCD camera covering about 1 deg^2 at a scale of 1.67 arcsec/pixel. No filter was used in front of the detector in order to achieve maximum sensitivity within the relatively short exposure allowed by

the field location, just beyond the local meridian at sunset. The resulting band peaks at ~ 700 nm with a FWHM of ~ 300 nm, corresponding roughly to $0.5F_V + F_R + F_I$ when referred to the Bessel filter set. Each image was composed by dithering three frames taken in sequence after a small shift of the telescope pointing direction; each frame was exposed for ~ 500 s. The FWHM of the point spread function were ~ 4 , 4 and 3 arcsec on Feb 28, Mar 4 and Mar 12, respectively. The first observation took place between Feb 28.795 and 28.827 UT, starting only 16.1 hr after the onset of GRB970228 (Feb 28.124 UT $\equiv t_o$ (Costa *et al.* 1997)), *i.e.* ~ 4.5 hours earlier than the observation that led to the discovery of the Optical Transient in the Beppo-SAX error box of GRB970228 (VP).

Our image (fig. 1a) revealed an object at a position of RA $05^h 01^m 46.63 \pm 0.04^s$ and DEC $11^\circ 46' 54.7 \pm 1.0''$, consistent with the position of the Optical Transient (OT) reported in VP (we give maximum uncertainties throughout this correspondence). Some 3 arcsec to the SW at RA $05^h 01^m 46.52 \pm 0.04^s$ and DEC $11^\circ 46' 53.0 \pm 1.0''$, the nearby KM star reported in VP, Groot *et al.* (1997), Tonry *et al.* (1997) was visible but partially blended with the OT. Then, to extract the net fluxes of both sources, we applied an iterative debiasing routine showing that the transient was 1.6 ± 0.5 mag brighter than the KM star in our band. Aperture photometry on four nearby field stars, supposed constant and labelled 1, 2, 3, 4 in the figure, set the zero point of the magnitudes. This reference set showed a differential maximum error between different nights of less than 0.1 mag.

Further analysis on a short time scale (using separately the three frames of Feb 28) did not identify variability of the Optical Transient during the 50 minutes observation run, with a 3σ upper limit of about 0.7 mag. During our second observation (Mar 4.832 - 4.864 UT, see fig. 1b) the Optical Transient was not detected, while the nearby KM star was still observed at a level compatible with that of the first observation (0.5 mag uncertainty). An upper limit to the flux of the Optical Transient was derived and calibrated relative to our zero point using a detection limit equal to the 3σ sky background noise. We found that the Optical Transient decreased by at least 2.7 mag in our band between Feb 28.8 and Mar 4.8. This is consistent with a power law fading of the flux $\propto (t - t_o)^{-\alpha}$ with $\alpha \geq 1.3$. The images we obtained on Mar 12.8 had a substantially higher sky background due to the presence of the rising moon near the field of view and their limiting sensitivity was insufficient to detect either the nearby KM star or the Optical Transient. In order to convert our measurements to standard flux units we adopted the following procedure: we approximated our band with the following linear combination of the standard Bessel filters, $0.5F_V + F_R + F_I$. To transform our signal to μJy we referred the photometry to the magnitudes reported in VP for the KM dwarf, and dereddened it by means of the mean galactic absorption in the direction of GRB970228,

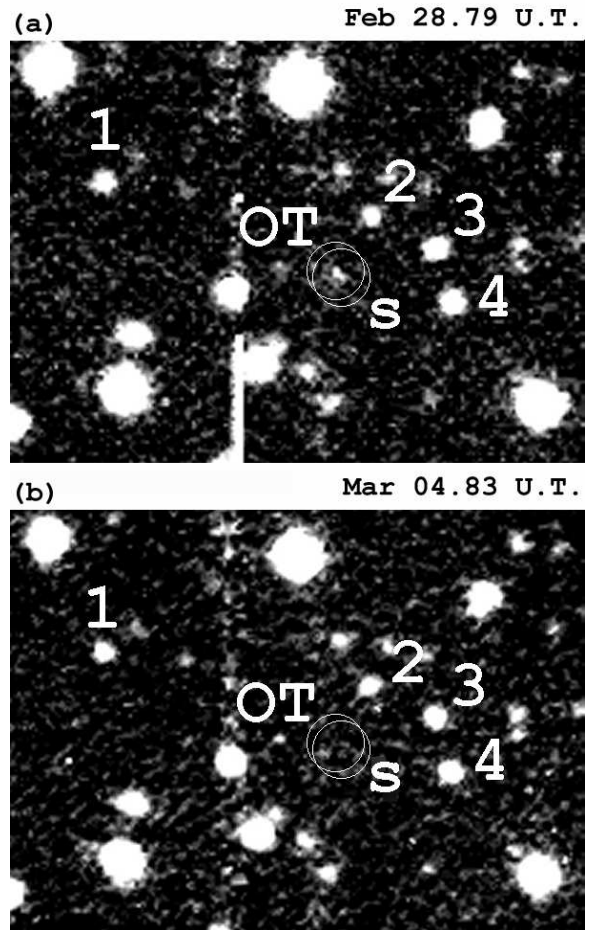


Fig. 1. CCD images of the field of GRB970228 taken at the 0.60 m Schmidt telescope at Campo Imperatore. The numbers indicate the reference stars, used to set the photometry zero point. The centers of the circles indicate the location of the Optical Transient (labelled OT) and of the KM star (labelled S). Each image covers a field of $\approx 2.8 \times 1.9$ arcmin². North and East are top and left, respectively.

$A_V \simeq 0.4$, $A_R \simeq 0.3$, $A_I \simeq 0.2$. For the star, $V - I \simeq 2.4$, implying a M2 spectral type and, in turn, $V - R \approx 1.2$. Assuming for the Optical Transient a power law spectrum with an energy index of 0.4 (consistent with the V and I measurements in VP) we derive a dereddened flux at 700 nm of $50 \pm 25 \mu Jy$ from our Feb. 28.8 image. By comparison, the I and V measurements obtained ~ 4.5 hours later (VP) correspond to an Optical Transient flux of $\approx 18 \mu Jy$ at 700 nm. If the flux decreases with time according to the law $\propto (t - t_o)^{-1.3}$, on the basis of the flux measured by VP we expect a flux of $\approx 27 \mu Jy$ at the time of our observations: this compares favourably with our measure of $50 \pm 25 \mu Jy$.

In short, we have confirmed the detection of the Optical Transient at a flux level comparable to that reported in VP, extended backward by ~ 4.5 hours the time range over which the transient was detected (see also Guarnieri

et al. 1997), shown that the time law for its fading is consistent with that of Galama *et al.* (1997) and proved the value of small easily accessible telescopes in the business at hand.

If the time-delay between the beginning of the X-ray afterglow and the onset of the optical is sufficiently short, the Optical Transient following GRBs may reach $m_V \approx 17$ a few hours after the burst, a time scale long enough for the detection of the burst in the Wide Field Cameras of Beppo-SAX to be analyzed and relayed to optical observatories. While these flux levels are unlikely to be accessible to all bursts, as shown by the cases of GRB970111 and GRB970402, detection of even a handful of them would allow spectroscopic investigations establishing their distance scale by, *e.g.*, showing absorption lines of Galactic or Extragalactic origin, like in GRB970508 (Metzger *et al.* 1997), or traces of the Lyman- α forest.

Further testing of the fireball model is also made possible by optical observations: in fact, the time-delay between the X-ray and optical onsets is predicted in this model. This is because, at least initially, most non-thermal electrons will be emitting at shorter wavelengths than the optical ones, so that the onset of optical emission must wait for the peak of synchrotron emission to enter the optical waveband. This is especially sensitive to the time-evolution of the bulk Lorentz factor, which might be considerably affected by the presence (or lack thereof) of surrounding matter. Together with the time-evolution of the X-ray afterglow luminosity, this may yield valuable information on the environments in which GRBs go off (Vietri 1997b).

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